# Fuzzy Multi Criteria Decision Making Applications: A Review Study

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***Abstract:*** Fuzzy Multi Criteria Decision Making (FMCDM) techniques have a wide range of applications. However, they have different range of usage in various applications. In some applications they are more applied than others. In this study, we aim to investigate the most usage of FMCDM techniques among various applications. We select 150 articles that used FMCDM techniques for decision making. Then we analyzed the articles to investigate the application of FMCDM techniques. Finally, we found that "Location management" and "Supplier Selection" are the most applications for FMCDM techniques and among FMCDM techniques Fuzzy AHP and fuzzy TOPSIS are the most applied techniques.

***Keyword:*** MCDM, Fuzzy, AHP, TOPSIS, Review, Applications

## 1 Introduction

Today decision making problems in industries and manufactures have become more complex and difficult because development of information technology and accessing internet lead to increase the number of alternatives so decision makings should be critically and carefully. Complex decision problems with a lot of factors, Alternatives and comparisons force managers and decision makers get help from the advanced Decision Support System (DSS) with more efficient techniques. Multi criteria decision making (MCDM) methods are utilized in DSS to solve decision making problems with more than one criterion [1]. Most well-known MCDM methods are AHP (Analytic Hierarchy Process) proposed by Saaty [2], TOPSIS (Technique for Ordering Preferences Simulation to Ideal Solution) [3] , PROMETHEE and ELECTER . Conventional MCDM methods do not deal with uncertainty. Therefore, fuzzy set theory can be applied to handle the uncertainty of the decision makers [4].

FMCDM techniques are decision analysis techniques integrated with fuzzy techniques. Fuzzy techniques wildly use in MCDM to deal with uncertainty and increase the accuracy of decision making. The fuzzy extension of MCDM methods such as: AHP [5, 6], TOPSIS [7, 8], ANP [9], VIKOR [10, 11] and DEMATEL [12] have been employed for different applications. Some studies reviewed the FMCDM techniques [13], also some studies reviewed the literature of MCDM techniques in special applications such as energy, environment, source management, supplier selection and planning [14-23]. However, fuzzy techniques have different range of usage in various applications. In some applications they are more applied than others. In this study, we survey the literature of Fuzzy MCDM applications to investigate the most usage of FMCDM techniques among various applications.

## 2 Data collection method

The data have collected in Sep 2013, by two search engines: first ISI web of knowledge search engine and second Google scholar search engine. We searched for articles which applied Fuzzy MCDM techniques to address decision makings using ISI web of knowledge search engine and randomly selected 100 documents to review along with them also more related and high citation articles with more than 50 citations in Google scholar fig.1.

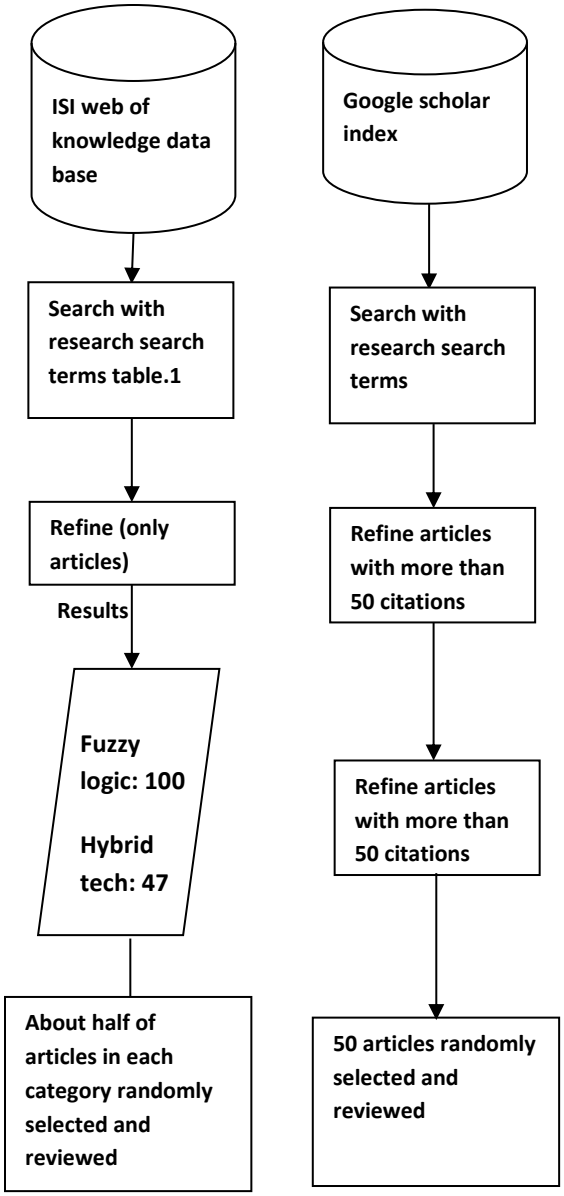


**Figure 1**. Data collection flowchart

## 3 Fuzzy logic

Fuzzy set theory has proposed by Prof.Zadeh [24], this theory solve the problem of uncertainty and ambiguous for computer systems with linguistic and vague variables. In intelligent decision support systems the aim is simulation of human thinking to make decision as human in difficult situations. DSS should refer to expert's knowledge for decision making so expert's knowledge should import to computer. Uncertainty is One of important factors to simulation of human's knowledge and linguistic therefore Fuzzy logic is the most consonant AI tools with DSSs and helps to import uncertainty and logic variable that is integrated with human knowledge to DSSs. Fuzzy logic widely has utilized in MCDM methods to optimize MCDM methods and created an extended approach named FMCDM (Fuzzy Multi-Criteria Decision Making ). FMCDM is a subset of Intelligent MCDM. During search in ISI web of knowledge data base there are 100 studies which use fuzzy technique to extend MCDM methods, this number is incomparable with other AI techniques. These studies mostly use fuzzy MCDM for evaluation, ranking and selection of alternatives, the Fuzzy set theory helps to numerized linguistic variables which used by decision makers regarding alternatives and criteria importancies. As the scope of FMCDM is very vast so it's impossible to survey all applications and methods in detail. Table.2 shows classification of articles according their applications.

**Table.2**.FMCDM applications

| Application | Articles | number | year | methods |
|---|---|---|---|---|
| Supplier selection | [6, 25-30] | 7 | 2009, 2011, 2008, 2012, 2011, 2007, 2008 | Integrated fuzzy model, fuzzy SOWT, fuzzy linear programming, Fuzzy AHP |
| Water resources | [31, 32] | 2 | 2011,2011 | Fuzzy TOPSIS, GIS-based MCDM method |
| Energy planning | [33-36] | 4 | 2009, 2009, 2010, 2010 | Fuzzy AHP, Fuzzy TOPSIS, Fuzzy VIKOR& AHP |
| Network selection | [37-39] | 3 | 2007, 2007, 2010 | Multi-objective optimization |
| Website selection | [40] | 1 | 2010 | |
| Location management | [41-50] | 10 | 2007, 2004, 2011, 2011, 2008, 2007, 2012, 2009, | Fuzzy AHP&GIS, fuzzy group decision making, fuzzy AHP&Fuz |

| | | | | |
|---|---|---|---|---|
| | | | 2012, 2004 | zy TOPSIS, GIS-based method, Fuzzy ANP, Fuzzy aggregation operator |
| Forest management | [51, 52] | 2 | 2004, 2011 | |
| Waste management | [53, 54] | 2 | 2011, 2011 | |
| Risk management | [55-57] | 3 | 2011, 2012, 2009 | Fuzzy TOPSIS, Fuzzy AHP |
| Product development | [58-60] | 3 | 2004, 2011, 2005 | |
| Transportation planning | [61-63] | 3 | 2012, 1999, 2011 | Fuzzy AHP, Fuzzy Delphi |
| Other | [64-70] | 7 | 2011, 2005, 2007, 2010, 2006, 1992, 2008 | |

## 4 Hybrid techniques

Hybrid techniques category is adopted from "hybrid systems" in [71, 72] and consist of Artificial Intelligent (AI) techniques integrated in MCDM. Mostly fuzzy logic is combined with other AI techniques to solve MCDM problems. Hybrid techniques utilized in MCDM are: Neuro-fuzzy, fuzzy-GA, fuzzy-ES. In hybrid techniques, AI techniques work together to solve problems in AI techniques to solve MCDM problems or to get better results for example there are some problems in ANN techniques to solve MCDM problems such as how to give a quantitative analysis for a large or a small learning rate and for large or small oscillation, how to find the correct global minimum without getting stuck at local minimum [73]. For different applications we have different integration of AI techniques.[74] has employed 3 AI techniques such as expert system, fuzzy logic and ANN with cooperate with AHP technique to design a flexible manufacturing system. This section surveys hybrid techniques in MCDM. From literature the most hybrid techniques in MCDM are: fuzzy logic and expert system, fuzzy logic and evolutionary algorithm, fuzzy logic and neural network, evolutionary algorithm and neural network which are explained in below.

1. *Fuzzy logic and expert system*
   Appling fuzzy expert system (FES) in MCDM is very common. Using FESs, the process of decision making in experts and their knowledge simulate. Because of using fuzzy logic, expert systems in this hybrid technique can handle both qualitative and quantitative properties. [75] has utilized FES for coating selection. [76] in this article FES is combined with AHP for supplier selection. [74] FES integrated with NN and AHP to design manufacturing system. [77] fuzzy case based reasoning methodology applied for sales forecasting. [78] in this study FES analyses the quality of airport service and combines with MCDM techniques to evaluate quality of airport services.[79] has applied FES for Colombia river salmon recovery plan. Also these articles [80-89] applied FES to solve MCDM problems whether combined with MCDM methods or applied alone as MCDM method.

2. *fuzzy logic and evolutionary algorithm*
   Fuzzy logic applies to complete and improve EA in decision making and many other applications which include uncertainty also EA can improve fuzzy system. Fuzzy set theory and EA can cooperate together in different versions for example in fuzzy system design, GAs can be used to tune membership values, prune membership functions and derive fuzzy rules. FL control can be applied to the operation of genetic systems and perform the evaluation function required in GAs. Figure 2 shows the process for use of a GA to improve the performance of a fuzzy system [90]. Variouce researchers have solved MCDM problems using combination of GA and fuzzy logic [91-106].

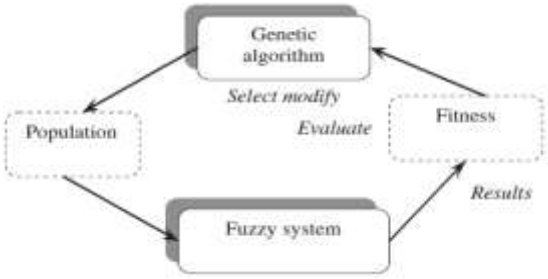


**Figure 2.** GA improves performance of fuzzy system

3. *fuzzy logic and neural network*

Neural networks can be improve using fuzzy techniques and produce a neural network with flexibility and high performance. There are two approach in cooperation between fuzzy and NN, one approach is to allow the fuzzy neural network to receive and process fuzzy input and another is to add layers on the front end of the network to fuzzification crisp input data to the fuzzy neural processing [90]. The fuzzy neuron is a fundamental concept used in many approaches to integrate fuzzy and neural technologies. In networks that map fuzzy input to crisp output, nodes in every layer of the network can have modified neurons. The input vector consists of a set of fuzzy values and the weights connecting the node with nodes in the previous layer also have fuzzy values. Input values and the weights are each represented by membership functions. A modified summation process is used to find the product of the membership functions of the fuzzy inputs and weights and then add the resulting membership functions to obtain another one that represents the integration of weighted fuzzy inputs to the node.

There are two used models for fuzzy neural systems:

a. In response to linguistic statements, the fuzzy interface block provides an input vector to a multilayer neural network. The neural network can be adapted (trained) to yield the desired command outputs or decisions (see Fig. 3(a)).
b. A multilayered neural network drives the fuzzy inference mechanism (see Fig. 3(b))

[74, 77, 100, 107-117] In these articles neuro-fuzzy technique integrated with MCDM techniques to solve MCDM problems.

4. *evolutionary algorithm and neural network*

NN can utilizes in Evolutionary optimization in a nonlinear, time-dependent process in combination with genetic algorithms [118]. [119] this article has used evolutionary neural network for selecting flexible manufacturing systems under disparate level-of-satisfaction of decision maker.

Fuzzy has been utilized in MCDM in many different applications using different methods which it is out of this study to survey all methods and application of fuzzy MCDM methods and we put it for future work. In this study we surveyed 47 FMCDM articles in face of applications. We found that FMCDM methods apply for location management more than other applications Fig. 4.

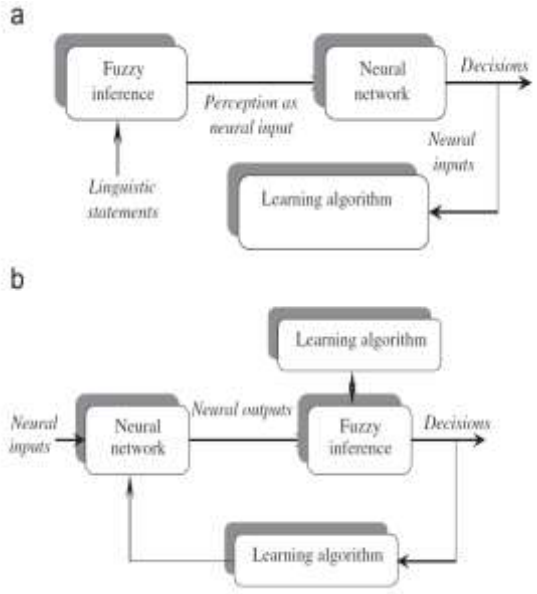


**Figure 3.** (a) First model of fuzzy neural system, (b) Second model of fuzzy neural system[90]

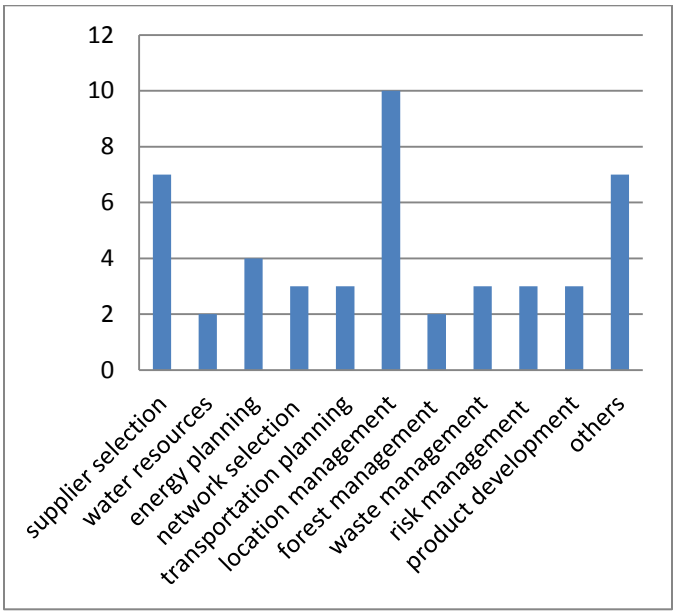


**Figure 4.**. Applications of FMCDM techniques

Recently using fuzzy logic in MCDM is increasing (fig.5) and h-index which reported by ISI web of knowledge for FMCDM is 12, this is the highest number of h-index among AI techniques.

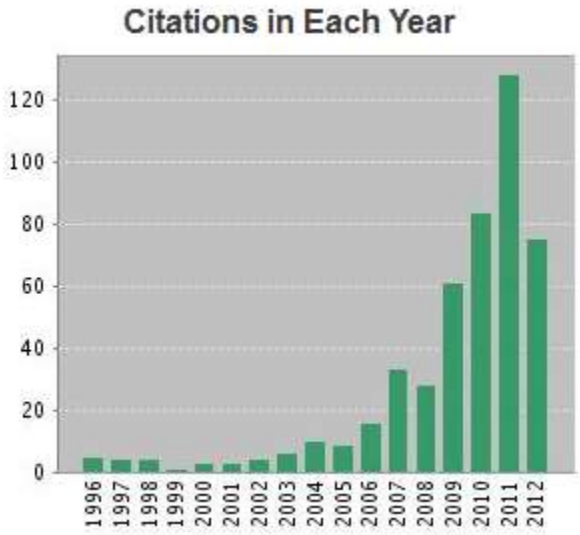


**Figure 5.**. Trend of FMCDM citation from ISI web of knowledge

Fuzzy has best integration with other AI techniques to solve MCDM problems. Fuzzy EA and fuzzy ES are more applicable than fuzzy ANN fig. 6.

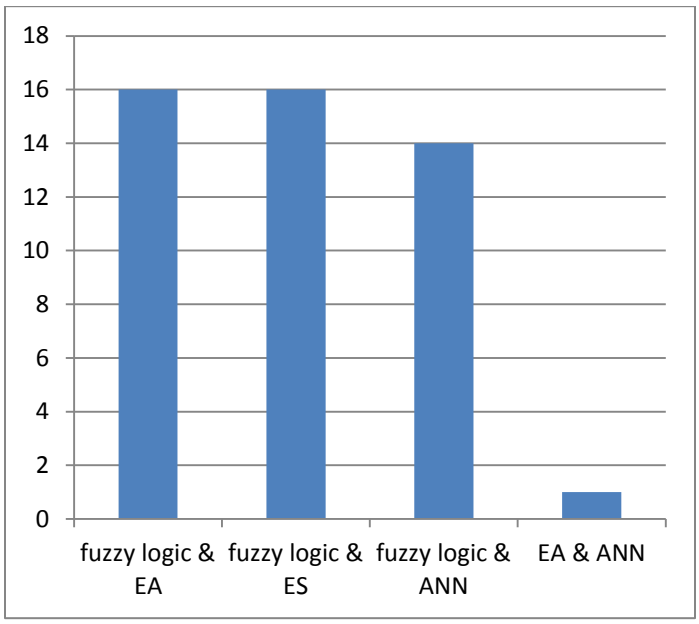


**Figure 6.** Hybrid techniques

## 5 Conclusion

This research has surveyed 250 articles and has reviewed 150 of them critically. The findings of this review are as bellow:

1. The most of AI techniques integrated with MCDM methods in order are fuzzy logic, hybrid systems, Expert Systems (ES), Evolutionary Algorithms (EA) especially genetic algorithms (GA), and artificial neural networks (ANN).
2. Most applicable and usable AI technique in MCDM is fuzzy logic that appears in 2 aspects:
   - Integrating with other AI techniques in hybrid techniques
   - Integrating with MCDM method
3. Fuzzy technique has been utilized in both categories of MCDM (MADM and MODM) but it is most suitable for MADM because most of the applications of FMCDM are in discrete decision makings environment.
4. Fuzzy MCDM mostly applies for location management and supplier selection.
5. EA, GA and ANN mostly utilized for MODM and decision making in continues environment like forecasting and predicting.
6. EA technique is second AI technique to apply in MCDM which mostly present as MCDM technique to solve MCDM problems.
7. EAs are most suitable for optimization decision making.
8. ANN always utilizes to calculate and prepare a criterion for MCDM.
9. ES mostly combines with GIS system for decision making in geographic field.
10. ES mostly integrated with MADM techniques like AHP for evaluation and selection.

This study has some limitations as we only reviewed articles from ISI web of knowledge data base and high citation articles in Google scholar index. Fuzzy MCDM is very wide area and this study didn't cover survey of methodology and methods in fuzzy MCDM. In future works we will survey fuzzy MCDM applications, application areas, methodology, methods and publications and we will propose a novel and optimized intelligent MCDM method for supplier selection.

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